Search for $t\bar{t} \rightarrow l\tau\nu\nu qq$ events in $p\bar{p}$ collisions at $\sqrt{s} = 1.96$ TeV

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Abstract. The search for top pair production in the dilepton signature with one electron (or one muon) and one tau decaying hadronically is discussed in this Note. The reported study is currently based on 350 pb-1 recorded data. The dominant backgrounds are $Z \rightarrow \tau_l\tau_{had}$, and events with jets faking taus predominantly coming from $W \rightarrow l\nu{+}jets$, $t\bar{t} \rightarrow l\nu{+}jets$ and QCD backgrounds. The probability for the 2.7 ± 0.4 expected background events alone to give rise to the observed number (5) or more is 15%. This is roughly equivalent to a 1-sigma excess over the expected background, but is in good agreement with the total number of events expected from signal and background together, 5.0 ± 0.5.

1. Introduction

The goal of this study is to extract the top pair events in which one top produces an electron or a muon, and the other top produces a tau decaying into hadrons, from the mass of events produced by the 1.96 TeV ppbar collisions at Tevatron. With the increase of the luminosity and the improvement of the detector compared to the first run (1993-1994), it will be hopefully possible during the Run II to establish for the first time a clear evidence of this still poorly known top channel.

This analysis requires to master the identification of all the fundamental objects: electrons, muons and hadronic decays of the tau lepton, eventually B jets. A good measurement of the missing transverse energies, and of the two jet Et is critical too. A good understanding of the most important backgrounds ($Z \rightarrow \tau_l\tau_{had}$, QCD with jets faking a tau hadronic decay, dibosons) in a high jet multiplicity environment is a prerequisite.

In this document, the physics motivations of this analysis will first be presented, followed by the event selection strategy and acceptance, an overview of the lepton identification, an explanation of the background estimation, and finally an account of the results obtained, verification methods and estimate of the uncertainty on the measured top in tau cross-section.

2. Physics motivations

2.1. Completing the study of all possible ttbar dilepton decays

In Run II, the increase from 1.8 to 1.96 GeV in the center of mass energy has yielded an increased theoretical cross section for the top pair production of $6.5pb$. More importantly, the higher luminosity produced by the Tevatron allowed CDF to record around $350pb^{-1}$ of data usable for this anlysis in September 2004, and around $1fb^{-1}$ at the end of 2005. $4fb^{-1}$ of data

Integrated Luminosity	$t\bar{t}$ $\rightarrow e + \tau_{had}$	passing geo and kine requirements	$t\bar{t}$ $\rightarrow \mu + \tau_{had}$	passing geo and kine requirements
350 $pb{-}1$	48	6.1	48	6.1
4 $fb{-}1$	551	69	551	69

Table 1. *MC estimates of top pair events produced in the two lepton + tau channels, assuming a cross section of 7.3 pb for the whole top pair production*

should hopefully be recorded and usable by the top analyses by 2008. The table **??** gathers the numbers of signal events expected to be produced in the two tau dilepton top channels.

CDF published in 2004 a first result using 195 pb^{-1} of Run II data

A first clear 3 σ observation of the top in tau channels should be first targetted and should be possible soon.

The optimization should be done here on $\frac{S}{\sqrt{B}}$.

2.2. Testing the lepton universality of the top coupling

Beyond the pure establishment of the signal, a measurement of its cross-section should be performed. The goal here is not really to help improving the precision of the overall measurement of the top pair production cross section (the tau dilepton channels cannot add significantly to the precision), but rather to check if the top quark couples the same way to tau leptons as it does to electrons and muons. Using the values obtained in the electron and muon dilepton top channels, a value of the ratio $R = \frac{t \rightarrow \tau \nu_\tau b}{t \rightarrow l \nu_l b}$ (l = e or μ) will me measured and compared to the value of 1 predicted by the standard model.

The optimization should be done here on $\frac{S}{\sqrt{S+B}}$.

2.3. A key-tool for beyond SM searches

Firstly, any value of R greater than 1 would be an indication of physics beyond the standard model. For instance, in the case of the existence of a charged Higgs, this one would couple preferently to the top quark because of its high mass. For the same reason, it would couple much more to the tau lepton than to the lighter leptons. The chain $t \rightarrow bH^+ \rightarrow b\tau\nu_\tau$ would yield greater than 1 R values.

More than 4 fb^{-1} would be certainly needed to establish a non 1 value of R. Waiting for more data, an upper limit can be set. With 195 pb^{-1}, CDF has already established that $R < 5$ at 95% confidence level [**?**].

Finally, a crucial aspect of that study is that a good understanding of signatures involving missing energy, several jets, two or three leptons, and especially τ leptons, is very important for the search of the supersymmetry. Indeed, these are typical SUSY signatures, and if $tan\beta$ is high enough, the rate of decays into τ leptons as compared to other processes becomes predominant. Therefore, being able to handle high multiplicity signatures including tau leptons is a new important achievement in hadronic colliders.

3. Event selection strategy and acceptance

The analysis presented in this document makes uses of 350 pb^{-1} of data collected at CDF in Run II until September 2004.

The data used for the signal measurement was triggered by the inclusive high P_t electron (or muon) trigger that requires an electron or a muon with a transverse energy greater that 18 GeV.

Subsequently, the offline selection requires:

- an identified isolated lepton (electron or muon) with $E_t > 20$ GeV, and pseudorapidities $|\eta| < 1$ to benefit from the whole tracking system performance
- an identified central isolated tau decaying into hadrons with $E_t > 15$ GeV. The identification is driven by the reconstruction of the 1 or 3 charged pions inside a narrow cone
- a missing transverse energy ($\not{E}_T$) greater than 20 GeV to account for the three neutrinos in the signal events
- two jets, one with $E_t > 25$ GeV, and the other one with $E_t > 15$ GeV
- a high activity in the event to account for the high top mass : the sum H_t of the four identified objects'transverse energies and of $\not{E}_T$ is greater than 205 GeV
- passes a veto against $Z \rightarrow \tau\tau + jets$ background

4. Signal and background estimation

4.1. The signal

The top signal is simulated with Pythia. The tau decay is handled by the Tauola package [**?**]. The CDF combined result obtained with 760 pb^{-1} is used for the $t\bar{t}$ cross-section [**?**]. A top mass of 175 GeV is assumed.

4.2. The irreducible background

This comes from backgrounds that present the same signature as the signal : $\not{E}_T$, one lepton (electron or muon), one tau decaying hadronically, and at least two jets. The main contribution is given by $Z \rightarrow \tau\tau + 2\ jets$ events where on tau is decaying leptonically and the other one semihadronically. Smaller contributions are furnished by diboson events, mainly WW + 2 jets.

These backgrounds'estimation is based on Pythia [**?**] and AlpGen [**?**] Monte Carlo packages. Scale factors are extracted from the $Z \rightarrow \mu\mu + 2\ jets$ sample to ensure that the predicted number of extra jets is compatible with the observations.

4.3. The reducible background

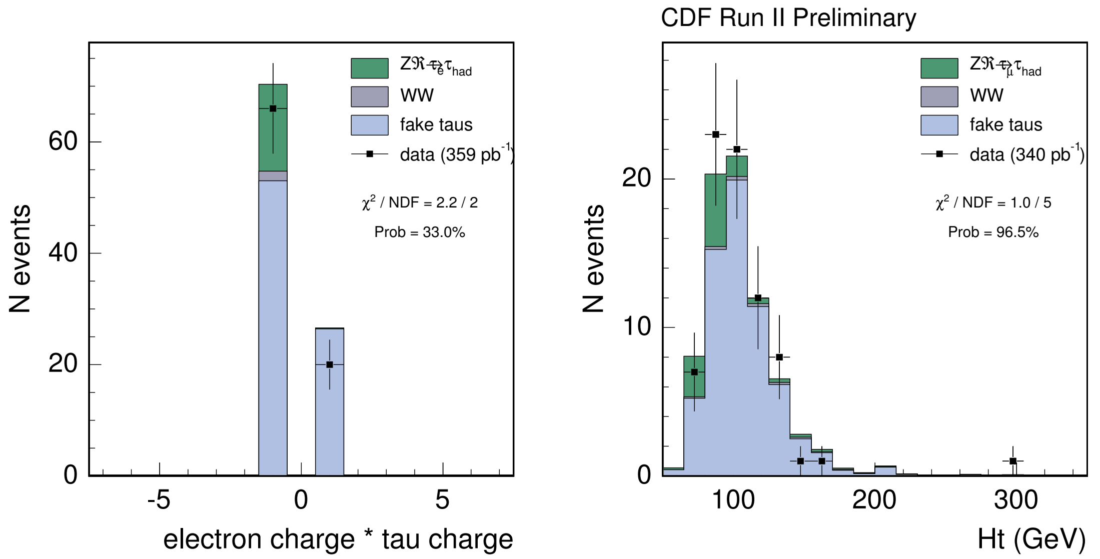
Events with no real tau but with jets or leptons misidentified as tau hadronic decays can end up into the final signal selection sample. These are largely dominated by events with jets faking taus and get a small contribution from events where an electron fakes a tau ($Z \rightarrow ee$ + 2 jets). Events where a muon fakes a tau are neglected.

To estimate the background where an electron fakes a tau, an electron to tau fake rate is measured from $Z \rightarrow ee$ data events. The number of events with tau candidates that fail the electron rejection requirement but pass all other analysis requirements are then scaled by the electron to tau fake rate.

The background where a jet fakes a tau is the dominant background in the analysis and also the trickiest to estimate precisely. W bosons with extra jets produced in association is the main source, but top pairs with one W decaying leptonically and the second one decaying into two quarks, and QCD events also contribute significantly. A method was developped to estimate the probability for a central jet to be identified as a tau (around 1%) in W+jets samples. The jet to tau fake rate function is parametrized with the jet transverse energy, the number of jets in the event and the sum of transverse energies deposited in the detector. The fake rate computed in QCD events with 1, 2, 3 jets was found to be compatible with the fake rate in $W \rightarrow l\nu + 1$, 2, *and* 3 *jets* samples respectively.

5. Control regions

Before looking at the number of observed events in the signal region, it is ensured that the prediction for the background is trustworthy. To do this, control regions are defined as the subsamples of events containing one identified lepton (electron or muon), one identified tau, missing transverse energy, and >= 0 or >= 1 extra jet. These control samples are dominated by $W \to l\nu + jets$ events. Checks are made for the number of events as well as for several kinematic distributions. The figure **??** shows distributions for the product of the electron charge and the tau charge and for H_t in the muon case. The high probabilities of consistency between the observed and predicted distributions ensure that the background estimation is under control.



(a) Charge product of the electron and the tau

(b) Event activity distribution in the muon+tau channel

Figure 1. *Two control distributions for events having 1 lepton, 1 tau, $\not\!\!E_T$>20 GeV*

6. Results

In the table **??**, are summarized the predicted signal and background events.

The knowledge of the expected number of events from the $t\bar{t} \to l\tau\nu\nu qq$ signal is not needed to achieve the first goal of this analysis, that is the mere establishment of the existence of the top tau dilepton signal.

Opening the box in the data, **5** events compatible with tau dilepton events are observed, summarized in the table **??**.

This is in agreement with the signal+background expectations and so well inside the sensitivity of this analysis.

The result is given in terms of probability for the 5 observed events to be due to background only, probability estimated by folding a Poisson distribution of mean 2.8 with a gaussian distribution of standard deviation 0.4, to be : **15%** (p-value). This constitutes a 1 sigma (68%) evidence of a first observation of the tau dilepton channel in $t\bar{t}$ production.

7. Acknowledgements

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	Electron + tau $359\ pb^{-1}$	Muon + tau $344\ pb^{-1}$
jet$\rightarrow \tau$ fakes	0.91 ± 0.29	0.92 ± 0.29
e$\rightarrow \tau$ fakes	0.10 ± 0.025	0.05 ± 0.012
$Z \rightarrow \tau_{\rightarrow l}\tau_{\rightarrow had}$+jets	0.39 ± 0.13	0.32 ± 0.10
$WW \rightarrow l\tau + jets$	0.034 ± 0.011	0.027 ± 0.008
Total Background	**1.4±0.3**	**1.3±0.3**
	2.8±0.4	
SIGNAL ($t\bar{t} \rightarrow l\tau\nu\nu qq$) (assuming $\sigma(t\bar{t}) = 7.3$ pb and $m_{top} = 175$ GeV)	$1.32 \pm 0.05_{stat.only}$	$0.92 \pm 0.05_{stat.only}$
	$2.2 \pm 0.1_{stat.only}$	

Total non Higgs standard model expectations	5.0±0.5
N events observed in 350 pb^{-1}	**5**

Table 2. *Summary of predicted signal and backgrounds vs observations*

channel	$l\ E_t$ (GeV)	$\tau\ E_t$	1^{st} jet E_t	2^{nd} jet E_t	$\not{E}_T$	H_t	N jets
$e+\tau$	68	20	35	33	72	228	2
$e+\tau$	42	40	69	40	53	244	3
$\mu+\tau$	42	44	62	55	100	302	2
$\mu+\tau$	29	44	102	96	29	301	4
$\mu+\tau$	53	31	49	48	36	216	2

Table 3. *kinematical characteristics of the 5 observed events. Energy unit is GeV.*

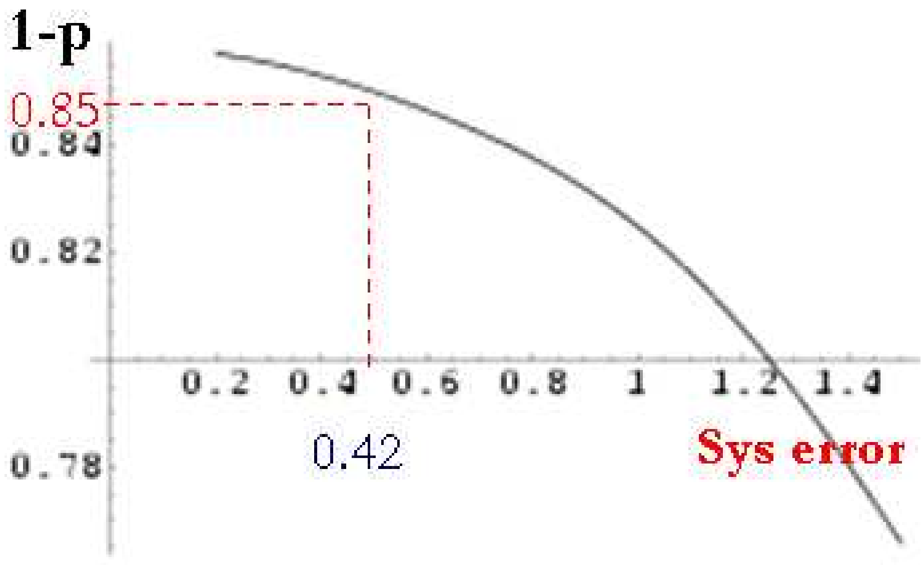

Figure 2. Dependence with the systematic error on the background of the probability for the background alone to fluctuate to 5 or more, with an expected mean number of 2.7 background events.

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